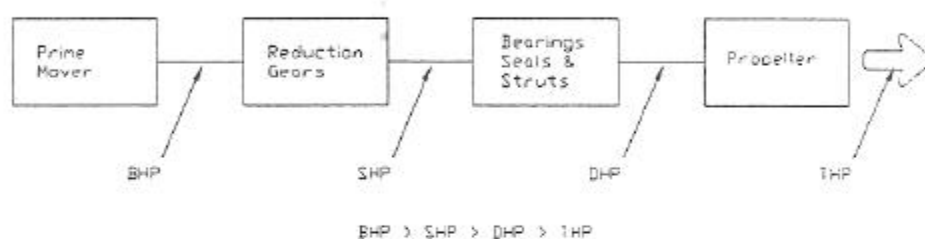


HOMEWORK SOLUTIONS - CHAPTER 7

Section 7.2

Ship Drive Train

1.
 - a. Draw a simplified picture of a ship's drive train with a prime mover, reduction gears, bearings, seals, struts, and propeller.
 - b. Show where the brake horsepower, Shaft horsepower, delivered horsepower, and thrust horsepower would be measured.
 - c. Rank the horsepowers in part "1.b" from highest in magnitude to lowest.



2. A ship with a drive train arrangement illustrated by Figure 7.1 has the following mechanical efficiencies.

Reduction Gearbox	95%
Bearings/Seals/Struts	98%
Propeller	68%

Calculate the Thrust Horsepower being created by the propeller when the prime mover has a Brake Horsepower of 10,000 HP.

$$\text{Thrust Horsepower} = 10,000(\text{HP}) \cdot 0.95 \cdot 0.98 \cdot 0.68$$

$$\text{Thrust Horsepower} = 6,331(\text{HP})$$

Section 7.3

Effective Horse Power

3.
 - a. What is effective horsepower? In your description give its symbol and units.
 - *Effective horsepower is the power required to move the ship at a given speed without the action of its propeller.*
 - *EHP (HP)*
 - b. How is EHP determined in the design of a ship?
 - *EHP is determined by performing a Froude Expansion on towing tank data obtained for a scale model of the ship.*

Hull Efficiency

4. Briefly explain why is it possible to have a hull efficiency greater than 100%.

The propeller efficiency is calculated for the propeller operating in "open water" conditions (smooth laminar flow). By careful hull design, the flow into the propeller can be enhanced improving overall efficiency - consequently hull resistance can be > 100%.

Section 7.4

Propulsive Coefficient

5. Towing tank testing has predicted that a ship will have an EHP of 33,000 HP when traveling at 25 knots. What will be the required SHP if the ship has a propulsive coefficient of 0.6?

$$\text{Propulsive Coefficient (PC)} = \frac{\text{EHP}}{\text{SHP}}$$

$$\text{SHP} = \frac{\text{EHP}}{\text{PC}} = \frac{33,000 \text{ HP}}{0.6} = 55,000 \text{ HP}$$

6. A twin screw ship has the following power data.

Ship Speed (kts)	EHP (Hp)
0	1
6	50
10	110
11	180
12	250
13	360
14	520
15	820

- a. Plot the power curve for this ship. Remember to label the axis correctly.

See Graph

- b. Assuming a propulsive coefficient of 0.55, calculate the top speed of the ship when it is running on both engines delivering 700 HP each.

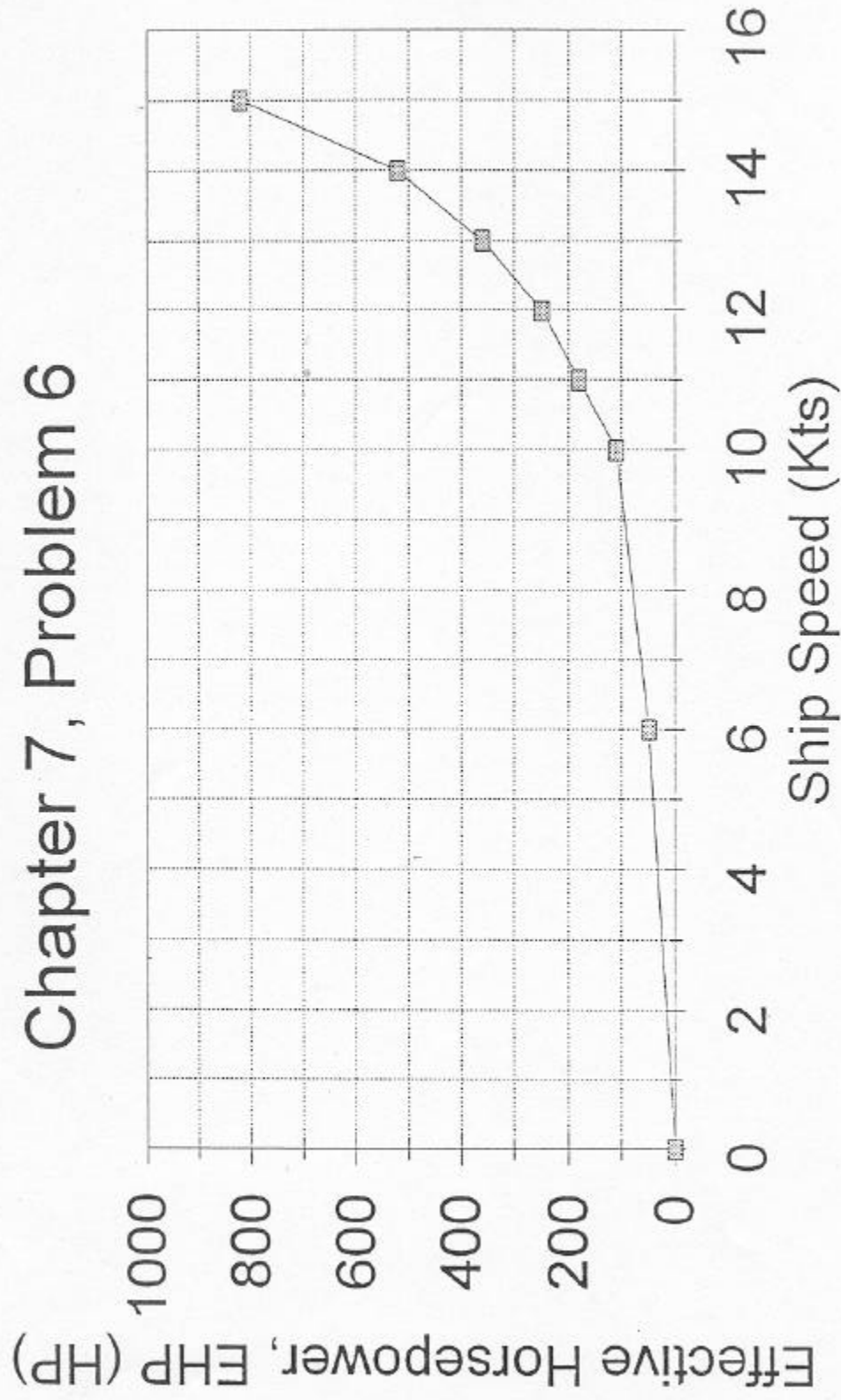
$$\text{EHP} = \text{BHP} \cdot \text{PC} = 2 \cdot 700 \text{ (HP)} \cdot 0.55 = 770 \text{ (HP)} \quad \rightarrow \quad V_s = 14.8 \text{ Kts}$$

- c. Assuming the same PC, calculate the speed of the ship operating on one engine rated at 700 HP.

$$\text{EHP} = \text{BHP} \cdot \text{PC} = 700 \text{ (HP)} \cdot 0.55 = 385 \text{ (HP)} \quad \rightarrow \quad V_s = 13.1 \text{ Kts}$$

Power Curve

Chapter 7, Problem 6



Section 7.6

Components of Total Resistance

9. a. Name the components of total hull resistance as calculated for the EHP of a ship in calm water.

Viscous resistance

Wave making resistance

Correlation allowance

- b. Which component dominates at slow speeds?

Slow speed - Viscous resistance dominates

- b. Which component dominates at high speeds?

High speed - Wave making resistance dominates

17.

What measures can be taken to reduce the Coefficient of Wave Making Resistance of a ship?

A bulbous bow is one attempt to reduce the wave making resistance of surface ships. Ideally the bulbous bow creates a second bow wave which interferes destructively with the normal bow wave. This interference would ideally result in no bow wave but normally results in a reduced or smaller bow wave.

Also, the "hull speed" of a ship can be increased by increasing the length of a ship.

Other Types of Resistance

18.

Name and explain four other types of resistance not included in the total hull resistance.

Appendage Resistance: Drag caused by underwater appendages, including propeller shafting, bilge keels, struts, rudders, and any towed equipment. Can account for 2-14% of total resistance.

Steering Resistance: Drag created whenever rudder is moved off centerline.

Air and Wind resistance: resistance caused by flow of air over ship. This component is effected by area and shape of ship above the waterline, wind velocity and direction. Accounts for between 4-10% of total resistance.

Added resistance due to Waves: Not to be confused with Wave Making resistance, this refers to ocean waves, which would be present without the ship, that impact on the ships forward motion. Any energy needed to overcome these waves and the motion they induce on ship is wasted energy.

Increased Resistance in Shallow Water: See Q17 below.

19.

Why does it take more power to do the same speed in shallow water than in deep water?

The flow around the bottom of the hull is restricted in shallow water, therefore the water flowing under the hull speeds up. The faster moving water increases the frictional resistance and also lowers the pressure under the hull which tends to suck the ship deeper into the water.

20. How can the operator take advantage of environmental factors to reduce resistance?

Wind and current are two of the biggest environmental factors affecting a ship. Wind resistance on a ship is a function of the ship's sail area, wind velocity and direction relative to the ship's direction of travel. For a ship steaming into a 20-knot wind, ship's resistance may be increased by up to 25-30%.

Ocean currents can also have a significant impact on a ship's resistance and the power required to maintain a desired speed. Steaming into a current will increase the power required to maintain speed.

Therefore, the prudent mariner will plan his or her voyage to avoid steaming against ocean currents and prevailing winds whenever possible, and to steam with currents and winds whenever possible.

21. Briefly explain the terms geometric similarity and dynamic similarity.

***Geometric similarity* is obtained when all characteristic dimensions of the model are directly proportional to the ship's dimensions.**

$$\text{Scale Factor} = \lambda = \frac{L_S(\text{ft})}{L_M(\text{ft})}$$

***Dynamic similarity* means that the velocities, accelerations, and forces associated with fluid flow around both the model and full-scale ship have scaled magnitudes and identical directions at corresponding locations along the hull.**

22. Explain how geometric similarity and partial dynamic similarity are achieved in resistance testing.

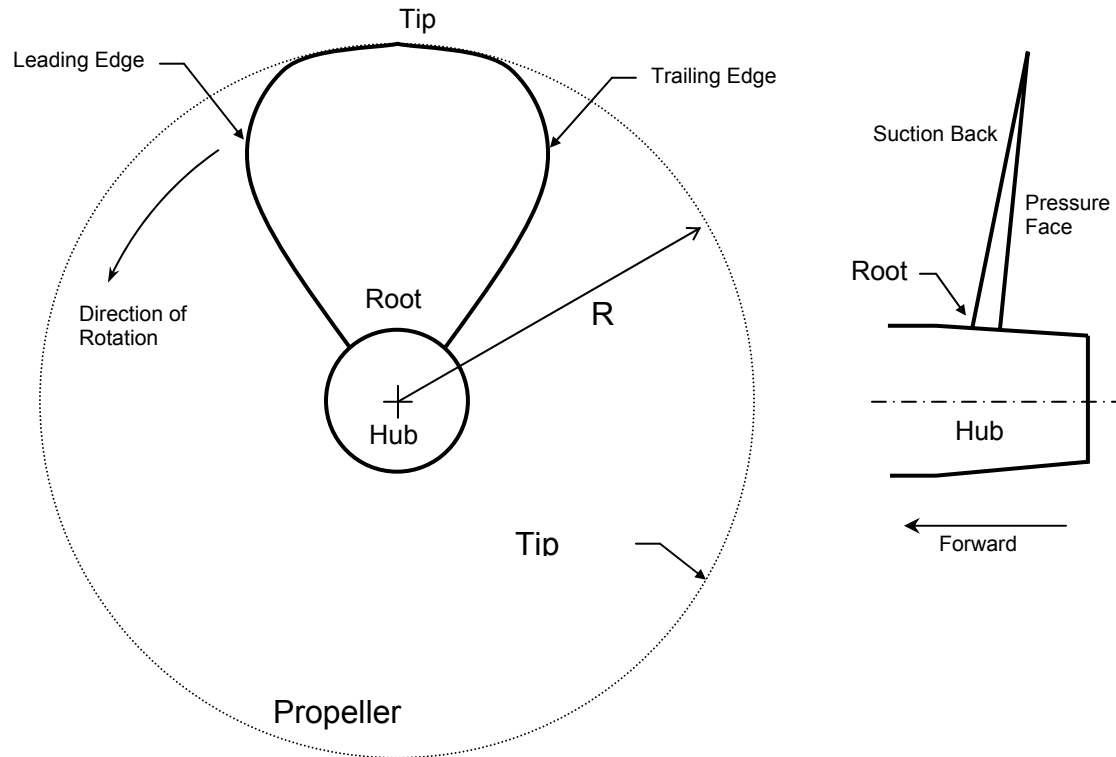
The wave pattern produced by a geometrically similar model and ship looks the same when the model and ship are traveling at the same speed to square root of length ratio. This is the Law of Corresponding Speeds, and is written as:

$$\frac{V_S}{\sqrt{L_S}} = \frac{V_M}{\sqrt{L_M}}$$

**where: V_S = ship velocity (ft/s)
 V_M = model velocity (ft/s)
 L_S = ship length (ft)
 L_M = model length (ft)**

Propellers

24. On a sketch of a screw propeller, show the hub, blade tip, blade root, propeller diameter, pressure face, and suction back.



25. Describe two methods for quantifying the pitch of a propeller.

Propeller pitch (P) is the ideal linear distance parallel to the direction of motion that would be traveled in one revolution of the propeller shaft; similar to what happens when you turn a wood screw one revolution into a block of wood.

The pitch angle (ϕ) of a propeller is the angle that any portion of the blade makes from perpendicular to the water flow. Since any point on a propeller blade describes a helix, the pitch of a propeller (P) and pitch angle are related through the following equation:

$$\tan \phi = \frac{P}{2\pi r}$$

26. Briefly describe the differences between fixed pitch, variable pitch, and controllable pitch propellers.

Fixed Pitch Propeller: A fixed pitch propeller is a propeller whose pitch is fixed and cannot be changed while the propeller shaft is rotating. A fixed pitch propeller may have either constant or variable pitch.

Variable Pitch Propeller: The pitch (P) varies at each radial distance from the blade root to tip. Additionally, the pitch may vary across the face of the blade from leading edge to trailing edge at any radial distance from the hub.

Controllable Pitch Propeller: This type of propeller allows the pitch of a propeller to be changed while the propeller shaft is rotating. This is accomplished by using an electro-hydraulic system to change the pitch angle of the blades. While the entire propeller is classified as a controllable pitch propeller, the blades can also be variable pitch, producing a controllable variable pitch propeller.

27. A propeller is described as having a pitch of 15 feet. What does this mean for the ship's operator?

Propeller pitch (P) is the ideal linear distance parallel to the direction of motion that would be traveled in one revolution of the propeller shaft; similar to what happens when you turn a wood screw one revolution into a block of wood.

A propeller pitch of 15 feet indicates that the propeller would ideally advance 15 feet forward for every revolution. In reality, the propeller will not advance a full 15 feet due to inefficiencies inherent in propellers.

28. Using the equations for the thrust loading coefficient and ideal propeller efficiency, answer the following:

- a. Will a larger propeller be more or less efficient than a smaller propeller?

Given the equations for propeller efficiency, $\eta_i = \frac{2}{1 + \sqrt{1 + C_T}}$ and propeller thrust loading

coefficient, $C_T = \frac{T}{\frac{1}{2} \rho A_0 V_A^2}$, we can see that as the area (A_0) increases, the thrust loading

coefficient C_T , decreases. As the thrust loading coefficient (C_T) decreases the propeller efficiency η_i increases as the denominator gets smaller.

- b. Will high thrust and low ship speed give high or low efficiency?

As Thrust (T) increases and ship speed (V_A) decreases, the thrust loading coefficient (C_T)

increases as is shown in the equation, $C_T = \frac{T}{\frac{1}{2} \rho A_0 V_A^2}$. As the loading coefficient (C_T)

increases, the propeller efficiency η_i decreases as is given by $\eta_i = \frac{2}{1 + \sqrt{1 + C_T}}$

29. Briefly describe why propeller cavitation occurs.

Cavitation is the formation and subsequent collapse of vapor bubbles in regions on propeller blades where pressure has fallen below the vapor pressure of water. Cavitation occurs on propellers that are heavily loaded, or are experiencing a high thrust loading coefficient.

30. What is the relationship between thrust loading and propeller cavitation?

An analysis of the equation for the thrust coefficient (C_T) reveals that high propeller thrust (T) and low speed through the propeller (V_A) increases the thrust loading coefficient which may result in cavitation.

$$C_T = \frac{T}{\frac{1}{2} \rho A_0 V_A^2}$$

31. Explain the following terms:

a. Tip cavitation

Blade tip cavitation is the most common form of cavitation. Tip cavitation forms because the blade tips are moving the fastest and therefore experience the greatest dynamic pressure drop.

b. Sheet cavitation

Sheet cavitation refers to a large and stable region of cavitation on a propeller, not necessarily covering the entire face of a blade. The suction face of the propeller is susceptible to sheet cavitation because of the low pressures there.

c. Spot cavitation

Spot cavitation occurs at sites on the blade where there is a scratch or some other surface imperfection.

32. What measures can the operator take to minimize propeller cavitation?

- **Speed** **Every ship has a cavitation inception speed, a speed where tip cavitation begins to form. Unless operationally necessary, ships should be operated at speeds below cavitation inception.**
- **Thrust** **For ships with manual throttles (steam turbine), the Throttleman must not increase shaft speed and thrust too quickly when accelerating the ship.
The Throttleman should open the throttle slowly, allowing flow velocity to increase or decrease proportionally with propeller thrust. Ships may use an acceleration table to guide the Throttleman in opening throttles or hydrophones calibrated to detect cavitation from the propeller.**
- **Pitch** **Operators of ships with controllable pitch propellers must take care that propeller pitch is increased or decreased in a smooth manner. This is usually done as part of the ship's propulsion control system. Incorrect operation of the pitch control system may cause high thrust loading on the propeller blades and increase the likelihood of cavitation.**
- **Depth** **Since cavitation is a function of hydrostatic pressure, increasing hydrostatic pressure (i.e. depth) will reduce the likelihood of cavitation. As a submarines depth increases, hydrostatic pressure increases and cavitation inception is delayed. Therefore, a submarine can operate at higher speeds at deeper depths with little worry about cavitation noise**
- **Fouling** **The propeller must be kept unfouled by marine organisms and free of nicks and scratches. Even a small scratch can cause significant spot cavitation and result in an increase in radiated noise as well as erosion of the blades. The Navy conducts regular underwater inspections and cleaning of its propellers to prevent the effects of fouling.**